X62 10164

CLASSIFICATION CHANGE
TO - UNCLASSIFIED
By authority of T.D. No. 24-231
Changed by O. L. Prewitt Date 3/22/24

RADIATION FROM WAKES OF BLUNT BODIES AT SPEEDS UP TO 32,000 FEET PER SECOND (Confidential)

Jack D. Stephenson

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, Calif.

CCN

Experiments to measure the optical radiation from the wake region of small-scale blunt bodies in flight at speeds up to 32,000 feet per second and at free-stream air densities from 0.003 to 0.18 atmosphere have furnished spectral distributions and magnitudes of the radiation in the range of wavelengths from 0.21 to 1.0 micron. The radiation was found to depend significantly upon the material of which the models were made. An important fraction of the radiation was in the near infrared.

When the air density was decreased in the tests, the radiation per unit volume in the wake became comparable in magnitude to that of equilibrium air in the shock layer, and the rate of attenuation of the wake luminosity with distance behind the model was reduced considerably. The total peak radiation per unit volume varied in proportion to the ambient density at velocities below 23,000 feet per second, and the spectrum of the wake was essentially constant with distance behind the model at least to a distance of 15 diameters.

1. INTRODUCTION

Most of the available information on luminous wakes applicable to the problem of missile detection and discrimination has been obtained by ground observation of flight vehicles. This method of acquiring the information does not lend itself to determining the effects of a large number of variables, and the measurement of many details of the radiation originating in the wake is precluded by practical limitations of instrumentation. It appeared that the data from missile flight experiments could be supplemented with laboratory tests by use of radiation measuring equipment which is available at the Ames Research Center. It was also expected that detailed information on the wake optical radiation might be useful for correlation with other studies of wake characteristics, such as laboratory measurements of electron densities, radar absorption, and thermal characteristics of wakes. Analysis of radiation traces for the wake regions of blunt models was therefore undertaken. Much of the data analyzed was available from previous studies of gas-cap radiation, such as that reported in reference 1.

(NASA-TM-X-70064) RADIATION FROM WAKES OF BLUNT BODIES AT SPEEDS UP TO 32000 FEET PER SECOND (NASA) 11 p

N74-74256

Unclas
00/99 36485

Early in the test program it became evident that the characteristics of the observed radiation, in the UV, visible, and IR regions of the spectrum, were closely associated with the ablation materials of which the models were constructed. The radiation from the air in the wake was usually at such a low level, relative to the radiance of the ablation products, as to be obscured.

2. EQUIPMENT AND APPARATUS

An experimental research facility developed to measure radiative heating at supersatellite velocities has been used to measure optical radiation in the wakes of small-scale blunt bodies flying at speeds up to 32,000 feet per second. The facility consists of a shock-tube-driven hypersonic wind tunnel in combination with a light-gas-gun type of model launcher. Models are observed in flight in the wind-tunnel air stream at three instrumented stations, spanning a distance of 2.7 feet. Figure 1 illustrates the test facility. The helium driven shock tube on the left supplies high enthalpy air for a 5,600 fps air stream in the 7.5-inch diameter test section. The light-gas gun on the right is capable of launching models 0.28 inch in diameter (and smaller) at velocities up to about 27,000 fps (ref. 2).

The wake information has been obtained with models of the two basic geometries shown in figure 2. Both had spherical segments of 0.2-inch radius as the forward faces. One type, which did not use a sabot, had a 0.28-inch-diameter cylindrical afterbody, 0.36 diameter in length. The other type, which was slightly smaller in diameter (0.22 in.) had a conical afterbody and was held in a two-piece plastic sabot during launching. The models were made of several plastic materials. One was the General Electric polycarbonate, Lexan, a commercially available thermoplastic. Two of the materials were epoxy-based resins referred to here by the manufacturer's number designations, G.E. 123B, and G.E. 124, which are thermosetting plastics selected for their special properties as charring ablation materials. In addition, results were obtained with polyethylene and phenolic nylon models.

The test section of the wind tunnel was instrumented to obtain the spectral distribution of the radiation from the shock layer in front of the model and from the wake. For this purpose, modules containing photomultipliers with relatively narrow band-pass optical filters were arranged like spokes of a wheel around the upstream (or downrange) station, as shown in figure 3. A pair of slits was mounted in the modules to provide a time and spatial resolution of the radiation signal. In most cases, the slits were 0.375 inch wide, but some results have also been obtained with the slit widths reduced to 0.05 inch. The spectral response characteristics of the eight modules were determined as part of the calibration procedure and are shown in figure 4. Here the relative response of each module, normalized to a peak value of unity, is plotted as a function of the wavelength. In addition to these modules, the radiation was measured with a broad band

photomultiplier tube (RCA 1P28) without a spectral filter. Its response curve is also shown in the figure. In studies of air radiation from the nose shock layer, it was found that the 1P28 tube could be calibrated to furnish an accurate measure of the total radiation from this source. It will be seen that the usefulness of this type of measurement is more limited when it is applied to wake radiation.

Besides the information from the photomultiplier tubes, model attitudes were recorded with spark shadowgraphs in two planes, and in some of the tests photographs of the self-luminous wakes and shock layers were obtained using a camera with a 50-nanosecond Kerr cell shutter. An example of such a photograph is also shown in figure 4.

3. RESULTS

Oscilloscope records showing the variation with time of the radiation at each module were analyzed. For each test, the spectral distribution at selected stations in the wake was computed and plotted in the form shown in figure 5, where the peak radiation energy in watts per micron per cubic centimeter is plotted as a function of wavelength. The volume used to compute these ordinates was based on a wake diameter estimated from the self-luminous photographs. This figure shows a comparison of results obtained with all of the various materials that were used. Model velocities were in the range from 20,000 to 23,000 fps. On the left the results are presented for a free-stream density of 0.018 times standard atmospheric density, and on the right the results are for 0.072 atmosphere. At both densities it is observed that for the different materials the radiation differed considerably both in spectral distribution and in total energy density. In particular, it is evident that the radiation from the wakes of the polyethylene models was much lower in intensity than that of the other materials. Also, it is apparent that within the spectral range covered by the detectors, a large fraction of the radiation is in the infrared. Efforts are now being directed toward extending the wavelength range of the detectors further into the infrared.

The vertical scales used in the two sets of data shown in figure 5 differ by a factor of 4. This is also the factor of increase in the ambient air densities of the two graphs. It is seen that for the Lexan models, neglecting the effect of the small difference in velocities, the integrated values of the radiation differed approximately in proportion to the densities, and the spectral distributions were influenced somewhat by the change in density.

All the data shown in figure 5 were obtained with models having the cylindrical afterbody geometry, with the exception of the phenolic nylon model which, because of limitations of mechanical strength, was sabot-mounted during launching and had the conical afterbody geometry. The effect of this difference in afterbody geometry was investigated and is indicated by the results presented in figure 6. This figure shows the same type of plot as the preceding one (at a lower density)

presenting results for two Lexan models, one of which had the cylindrical afterbody shape and was launched without a sabot, and the other had the tapered shape and was sabot-launched. The former model had a larger maximum diameter, 0.28 inch compared with 0.22, and flew at a slightly higher velocity than the sabot-launched model. It is seen that the spectral distributions for the two models are very similar. Also, if a factor is introduced to make the two sets of data correspond to the same velocity, it is found the data agree as well as data from identical models. This comparison of the results indicates that the method of launch did not have a large effect, and it also indicates that the wake radiation is influenced primarily by the forward face of the model and not by differences at the sides and afterbody.

The spectral distributions of the peak wake radiation have been integrated to give the total radiation per unit volume in the range from 0.21 to 1.0 micron. The data shown in figure 7 were obtained with Lexan models at velocities near 21,000 fps at densities ranging from 0.003 to 0.18 atmosphere, and also at velocities near 32,000 fps, at densities of 0.003 and 0.036 atmosphere.

The broken lines in figure 7 represent the (peak) radiation that was measured by the 1P28 broad-band detector. At constant velocities, the data from the 1P28 photomultiplier showing the effect of density agree well with the values given by the integration, although this detector does not respond to some important parts of the spectrum, and therefore does not furnish a satisfactory measure of the total radiation. It was sensitive to a much larger fraction of the radiation produced in the wake at 32,000 fps than at a speed of 21,000 fps.

At the lower velocity, 21,000 fps, the data in figure 7 indicate that the total radiation varied as the first power of the ambient density. This same dependence on density was measured with polyethylene and with G.E. 124. At the higher velocity, 32,000 fps, the total radiation increased much more slowly with density, the estimated value being about 0.5 power of the density.

The distribution of energy density in the wake was determined at distances of 15 diameters behind the models for three of the materials. In addition, this distribution was also determined with a polyethylene model at 30 diameters. Results of these measurements, examples of which are shown in figure 8, indicate that there was very little change in the spectral distributions with distance behind the model.

Inspection of the oscillograph records indicated that the decay of the radiation intensity could in many cases be approximated with an exponential damping curve. It was assumed that such a curve could be fitted to all the data, and the integrated values of radiation behind the models were used to calculate damping coefficients. The coefficients obtained in this manner were compared with those calculated from the 1P28 photomultiplier. From this comparison it was concluded that the 1P28 tube furnished a good basis for calculating the damping of the total wake radiation. A

damping coefficient K was defined by the equation

$$E/E_0 = e^{-K(x/d)}$$

where E_0 is the peak radiation density in the wake, and x/d is the downstream distance in model diameters. This coefficient is shown for the polycarbonates in figure 9 as a function of free-stream density. It is seen that the coefficients increased significantly with density, indicating a rapid attenuation with distance of wake luminosity at high ambient densities and a relatively low attenuation rate of the wake at low density or at high altitude. This can have a large influence on the detectability of the radiating wake at high altitudes.

Extensive studies have been made to predict the radiation energy of air in the shock layer, or so-called gas cap, at the front of blunt bodies. It was considered important to compare this radiation with that originating in the wake. The ratio of the measured wake radiation to the gas-cap radiation calculated for equilibrium conditions at the stagnation point from reference 3 is shown in figure 10 as a function of ambient density. The upper curve is for velocities near 21,000 fps and the lower one is for 32,000 fps. Both show substantial increases in wake radiation relative to gas-cap radiation with decreasing density. This is a consequence of the different density dependence of the two radiations. At the lowest densities, the wake radiation approaches the equilibrium air radiation from the shock layer. It is also evident that the velocity effect on wake radiation relative to gas-cap radiation depends strongly on the density.

The reference shock-layer radiation in figure 10 is based on equilibrium conditions. At low ambient densities, such as are represented by the left portions of the curves in this figure, the air radiation observed experimentally in the shock layer was much greater than the equilibrium values. At these low densities the shock layer was not in equilibrium, and conditions in the wake may also be influenced to a considerable extent by nonequilibrium effects.

4. CONCLUSIONS

Tests of ablating plastic models have indicated that the magnitude and spectral distribution of the wake radiation in the range of wavelengths from 0.2 to 1.0 micron depend importantly on the material that is used. A large fraction of the radiation was observed to be in the near infrared.

At velocities below about 23,000 feet per second, the tests showed that the total radiation per unit volume varied in proportion to the ambient density. At the lowest air densities of the tests, the radiation per unit volume in the wake became comparable in magnitude to that of equilibrium air in the gas cap. Lowering the ambient density also caused the rate of attenuation of the wake luminosity to be reduced. These observations suggest that for certain materials, at high altitudes, the wake luminosity can be a powerful source of radiation compared to the shock-layer radiation. This is in agreement with observations of flight vehicles entering the atmosphere.

Other conclusions from the tests were that the spectrum of the wake luminosity was essentially independent of distance behind the body, at least to a distance of 15 diameters, and that the afterbody shape had little effect in determining the characteristics of the wake luminosity.

5. REFERENCES

1. Page, William A., Canning, Thomas N., Craig, Roger A., and Stephenson, Jack D.: Measurements of Thermal Radiation of Air From the Stagnation Region of Blunt Bodies Traveling at Velocities up to 31,000 Feet per Second. NASA TM X-508, 1961.

2. Bioletti, Carlton, and Cunningham, Bernard E.: A High Velocity Gun Employing a Shock-Compressed Light Gas. NASA TN D-307, 1960.

3. Kivel, B., and Bailey, K.: Tables of Radiation From High Temperature Air. Res. Rep. 21, AVCO Res. Lab., 1957.

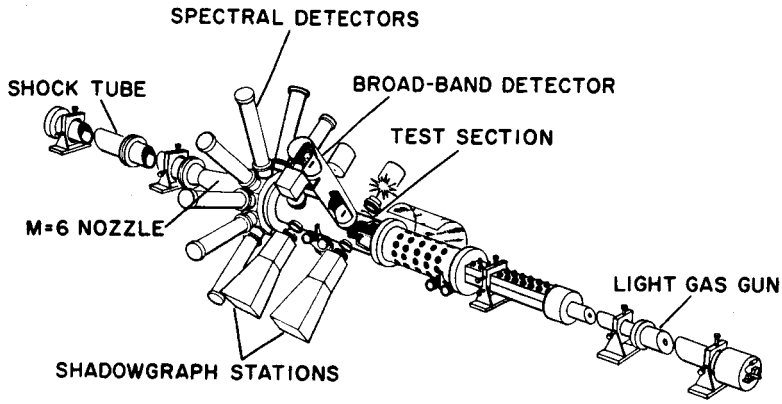

Figure 1

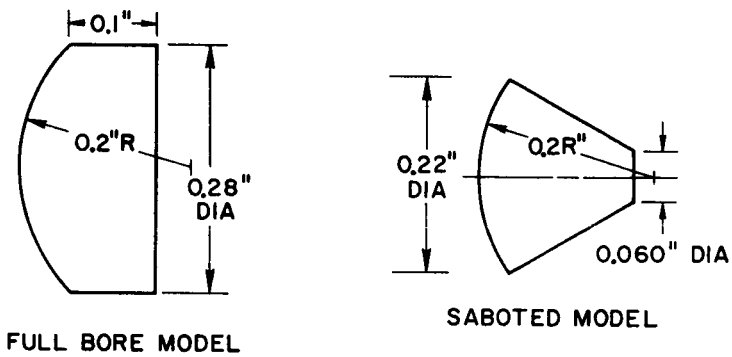

Figure 2

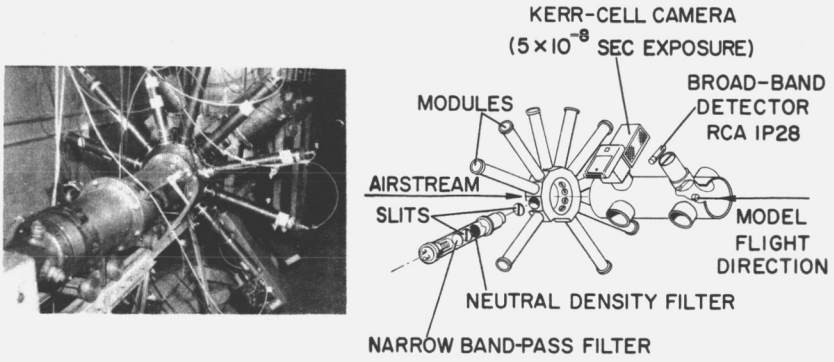

Figure 3

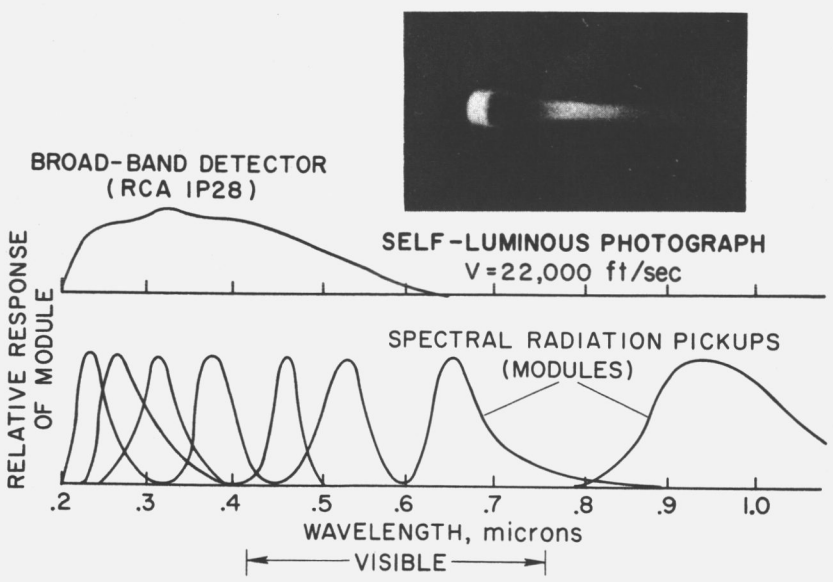

Figure 4

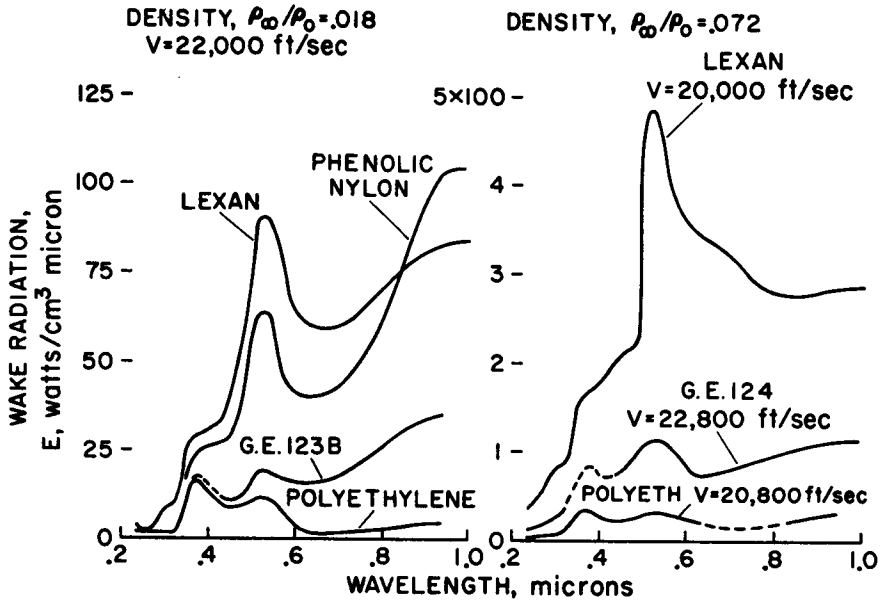

Figure 5

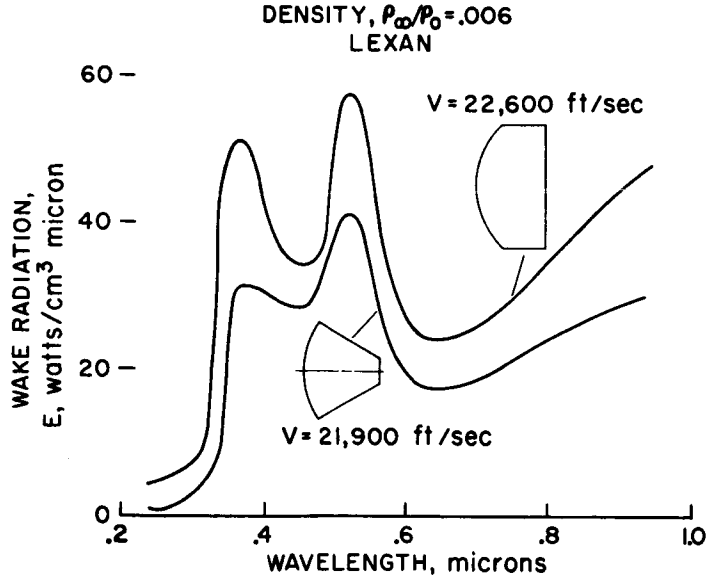

Figure 6

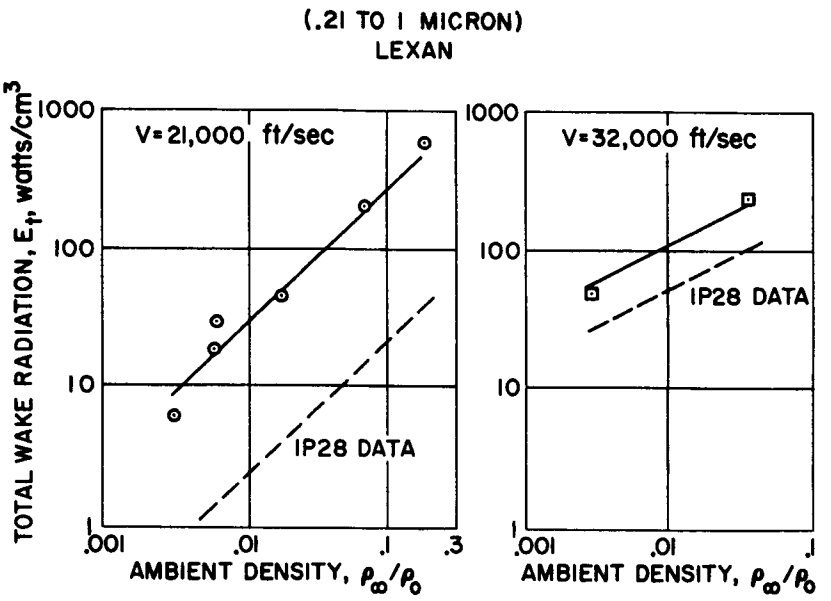

Figure 7

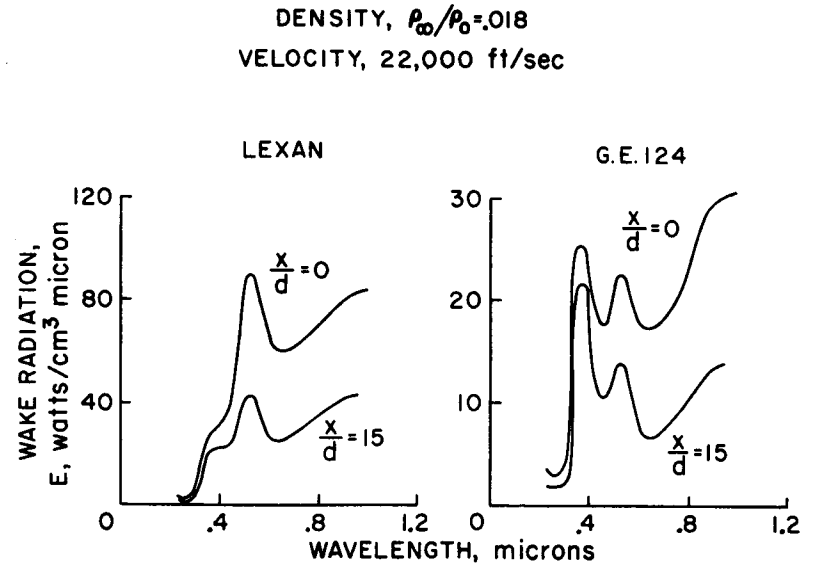

Figure 8

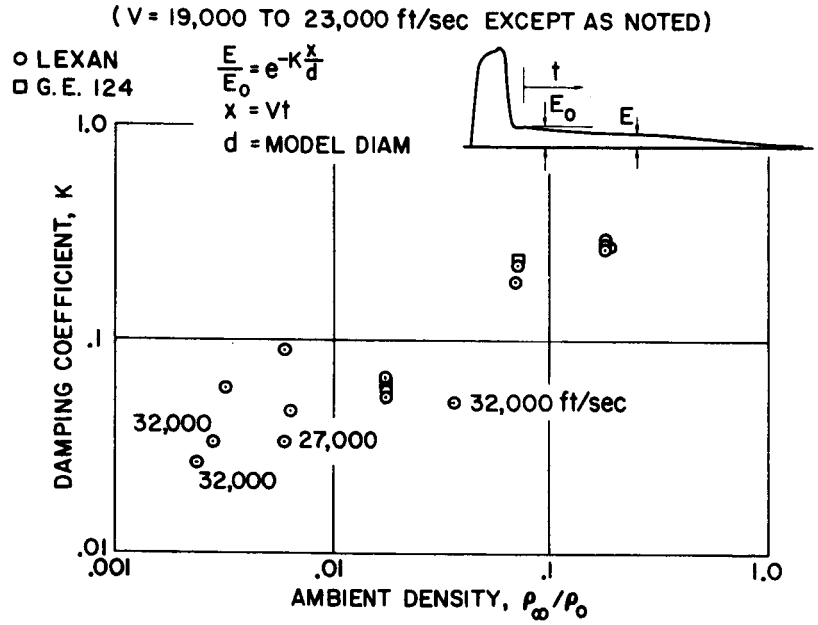

Figure 9

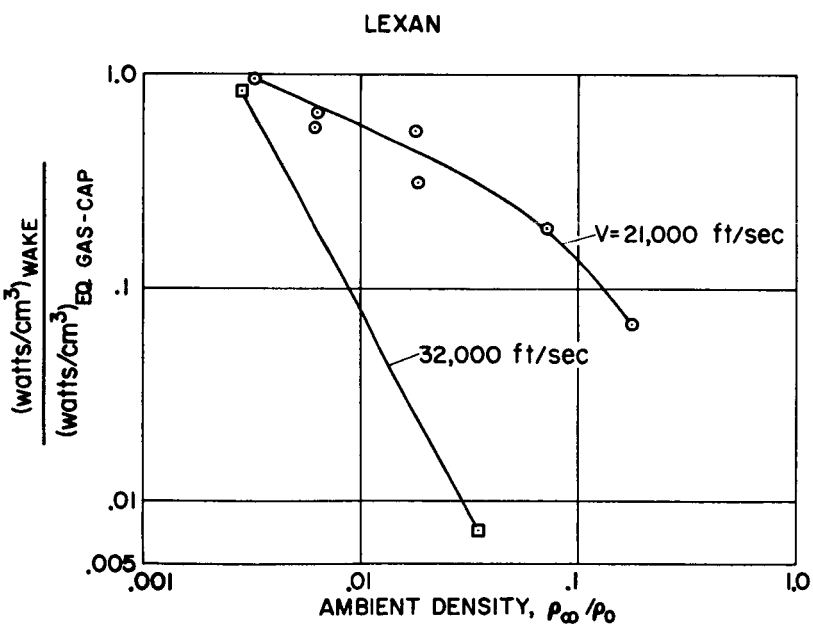

Figure 10